JONES

Electric Arc Lamps

Electrical Engineering

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ELECTRIC ARC LAMPS

BY

EDWARD WALTER JONES

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IN

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

Edward Walter Jones

ENTITLED Electric Arc Lamps

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Electrical Engineering

H. F. Hake
Instructor in Charge

APPROVED: Ernst Berg

HEAD OF DEPARTMENT OF Electrical Engineering.

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E L E C T R I C   A R C   L A M P S

HISTORY OF THE ELECTRIC ARC

In the year 1801 Sir Humphrey Davy, then a young man of 22, told in a lecture before the Royal Institution of a spark of "vivid whiteness" passing between two pieces of well burned carbon. The spark occured when the carbon rods were touched together and then separated while connected to the opposite poles of a galvanic battery. His source of energy was a battery of 250 pairs of copper and zinc plates placed in an electrolyte consisting of a solution of alum with a few drops of nitric acid added. Hence it is evident that simply a spark and not a continuous discharge resulted. In fact it was not until seven years later, in 1808 that the first true arc was produced. A huge galvanic battery of 2000 cells had been placed in the laboratory of the Royal Institution. With this source of power at his disposal, Davy produced the first continuous electrical discharge through air, the gap being about three inches long. Davy placed his carbon pencils,or rods, in a horizontal position and the upward current of heated air,together with the tendency to enlarge, caused the dis-

charge to take the form of an arch, and because of this fact, in the year 1820 he definitely named the electric flame the arc.

Until 1844 this phenomenon remained simply a brilliant laboratory experiment. In that year, however, Leon Foucault replaced the soft charcoal electrodes with sticks of hard gas retort carbon and, using the newly invented Bunsen battery, produced a steady and continuous light which was publicly exhibited in Paris. It attracted considerable attention and was utilized, in a small way, for the lighting of public squares and theaters. From 1844 on, inventors turned their attention to perfecting the lamp mechanism and it was soon developed to a rather high degree of efficiency. Because of its great cost, the inconvenience and labor involved in its care and maintenance, the weakening of the current and the evolution of obnoxious gases, the galvanic cell did not prove to be a commercial success as a source of energy. It was for this reason that no very extended use was made of the arc lamp until the discovery of magnetic induction and the invention of the electro-magnetic generator. This invention stimulated practical as well as scientific investigations and in 1878 the present series arc lamp with its shunt coil was devised. From this date improvements and inventions followed one another in rapid succession until the present high degree of development of the arc lamp has been attained.

THE GENERAL THEORY OF THE DIRECT CURRENT OPEN ARC

When two carbon rods are connected to the terminals of a battery or generator so that a constant difference of potential of forty volts or more is maintained and these rods are first brought together and then separated a short distance, a continuous electrical discharge takes place across the gap. This discharge is accompanied by a brilliant white light and the evolution of intense heat. The circuit is maintained through the gap due to the presence of volatilized carbon and carbon mist. This conducting strip of mist and vapor, called the arc stream, which bridges the gap, flows from the negative electrode toward the positive electrode. Therefore, the character of the arc stream is determined very largely by the composition of the negative electrode. It also follows that the temperature of the arc is probably that of the boiling of the material composing the negative electrode. In 1881 Sir Wm.Abney announced this deduction and said further that the temperature was constant. The temperature was given by M. Viole as 3500°C and by Rosetti as 3900°C. The temperature of the negative carbon tip is probably about 3000°C.

An exploration of the arc stream will show that it is by no means honogeneous. There is a thin layer of true carbon vapor covering the tip of the positive electrode; between this layer of vapor and the negative electrode the carbon is in the form of mist. The whole stream is surrcunded by a greenish flame produced by the carbon mist combining with the oxygen of the surrounding air. This flame is almost a perfect insulator and hence

plays no part in the conduction of current through the gap. The vapor near the positive electrode has a very much higher specific resistance than has the mist, and hence a large part of the energy consumed by the arc is absorbed in this layer of vapor and appears in the form of heat. It is this heat, in all probability, which causes the volatilization of the positive electrode. The volatilization of the positive electrode furnishes the carbon which is consumed or burned by oxidizing, and for this reason the positive electrode wastes away more rapidly than does the negative electrode, the ratio being about two to one in the ordinary open D. C. arc. This fact has given rise to the erroneous idea that the positive electrode feeds the arc stream. It does, however, furnish some of the carbon of the arc stream through heat evaporation. That the positive electrode does not feed the arc stream and its vaporization is not essential may be proved by making the positive electrode so large that the cooling effect prevents volatilization, when it will be found that the change in no way affects the operation of the arc.

Near the periphery of the electrode the vapor layer, covering the positive carbon tip, is cooled by the surrounding air into mist. Now since volatilization can occur only where the vapor is in actual contact with the carbon, it is evident that the inner part of the positive electrode tip is the only part of that electrode consumed by volatilization. This fact causes a hollow or crater, as it is called, to be formed in the positive carbon, leaving a rim at the periphery. This rim is itself consumed, or rather burned, by combining with the oxygen of the surrounding air, with varying degrees of rapidity depending on length of arc and value of current flowing. For a short arc

the consumption is slow and hence the crater will be deep. The rate of consumption increases with an increase of arc length. The depth of the crater varies in general with the current except for long arcs. Thus it would seem that an increase of arc length would decrease the crater depth and, in fact, both crater and rim practically disappear for arc lengths greater than diameter of positive electrode. The tip of the negative electrode is covered with carbon mist. Hence the negative electrode is not volatilised, but is heated partly by the carbon mist and partly by radiation from the positive electrode. The tip of the negative electrode being covered by mist is consumed solely by burning and through supplying the arc stream carbon. The sides of the electrode being heated to a rather high degree and being unprotected from the air, burn away more rapidly than does the protected tip. These sides are heated by the crater of the positive carbon and hence the negative tip will be longer and more slender the larger the crater and the shorter the arc. In general, the length of the tapering parts of both carbons is increased by increasing the current and decreasing the arc length.

If the current is sufficiently increased and arc length decreased, a mushroom tip is formed on the negative carbon. This mushroom tip is caused by carbon being deposited from the crater It interferes with the formation of the proper arc and obstructs the light from the crater. It is also undesirable in that it causes an unpleasant hissing noise. Hissing is an unstable condition of the arc and it may occur with any length of arc, provided the current is sufficiently large. The real distinction between the hissing and silent arcs is that in the silent arc

the crater occupies only the end of the positive carbon. The hissing seems to be due to the crater becoming too large to occupy the end of the positive carbon, and hence extends up the side of the carbon. The air then rushes in radially, burns the carbon very rapidly and produces the hissing sound. When hissing commences,a drop in arc voltage of from 10 to 20 volts occurs, after which the arc voltage remains practically constant for wide variations of current value.

The required difference of potential between the two electrodes depends on several factors. With metallic electrodes as little as 10 volts is sufficient, but with carbon electrodes not less than 40 volts will suffice. This impressed E. M. F. may be divided into three distinct parts. The first is the E. M. F. consumed from the positive carbon to the arc stream. Second the E. M. F. consumed in the arc stream proper. The third is the E. M. F. consumed from the arc stream to the negative carbon. The last or third is usually considered the true counter or back E.M.F. of the arc. The counter E. M. F. may also be defined as the difference between the impressed E. M. F. and that part of it which appears to obey Ohm's Law. Some investigators have observed a small back E. M. F. at the arc after the impressed E. M. F. was removed. It is approximately one volt and due to a thermal couple, the positive electrode being hotter than the negative. It was proved to be a true thermal E. M. F. by cooling the positive electrode when the E. M. F. was reduced and finally reversed.

The apparent resistance of the arc equals the current divided by the voltage. This apparent voltage may be represented by the equation a + bl. Here (a) is some quantity varying inversely

with the current, (b) is a constant and (l) the length of arc. In this equation (bl) is the true resistance, i.e., the ratio between a small increase in E and a corresponding increase of I. Multiplying this equation through by I we get, IR = Ia + blI. But IR equals E and Ia is the product of a quantity varying inversely as I and I itself, and hence may be expressed by a constant m. Ib may also be expressed by n and hence the equation reduces to:- E = m + nl. When good pure solid carbons are used, Duncan and Rowland give the value of m to be 40.6 and n to be 40 where l is expressed in inches.

By examining the equation given above for resistance, it will be noted that the resistance increases with a decrease of current and decreases for an increase of current. Hence it follows that when an arc is connected across a constant potential circuit it is unstable. This is due to the fact that if for any reason the current increases, the resistance will decrease and the current, therefore, increase to a very large value. Also, if the current begins to decrease,the resistance will increase and the arc go out. This necessitates some devise to steady the current. A suitable resistance in series with the arc performs this duty very satisfactorily. The reason will be made clear by examining Fig. 1 which is a typical stability curve. Here curve #1 is the volt-ampere characteristic of the arc itself, and curve #2 the R.I drop through the series resistance. Curve #3 is the resultant obtained by adding the ordinates of #1 and #2 together. If at any point on curve #1 there occurs an increase or decrease of current, the current will at once increase or decrease still more. If, however, the current increases or decreases at any

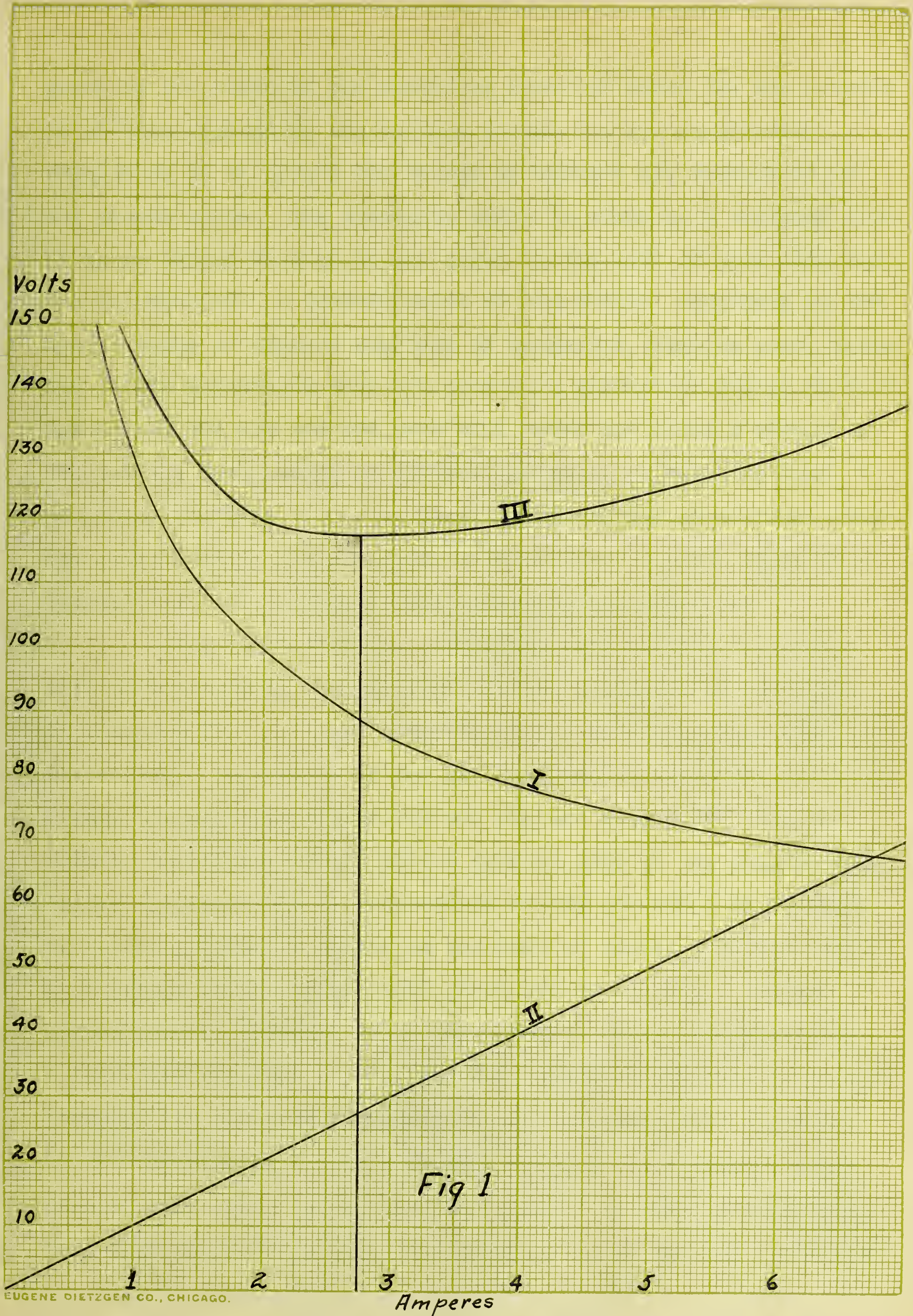
Volts
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
III
I
II
1
2
3
4
5
6
Amperes
EUGENE DIETZGEN CO., CHICAGO.

Fig 1

point to the right of the stability limit of curve #3, the trouble is at once righted as the voltage across the arc immediately changes so as to oppose the change of current and restore it to the proper value. The stability limit is shown by a vertical line. It is so called because at any point to the left of this line the arc is unstable. A correct value of resistance, depending on the normal value of current and type of mechanism, must be used, since too little resistance will not produce a sufficient change in voltage across the arc and too much will cause too great a change in arc voltage for changes of current too small to move the feed mechanism and will therefore permit large surges of current. Series resistance is not necessary with constant current lamps as a correct value of current is maintained by the generator.

The light from the carbon arc very closely approaches that of sunlight in composition. If the intensity of red light is taken as 100 the light composition is: red 100, green 200, violet 250. The crater of the positive carbon emits 85% of the light, the negative carbon 10% and the arc stream 5%. The intrinsic brilliancy of the crater depends only on the composition of the electrode and is independent of the current. An increase of current, however, causes an increase of crater area and hence an increase of the total light given off by the arc. The arc stream,itself, consists of an inner hub of violet surrounded by a thin dark envelope of CO. The outer portion or green flame surrounding the whole is caused by the CO combining with the oxygen of the surrounding air to form CO_2. Fig. 2 is a typical light distribution curve for an open D. C. arc. It will be noted from this that no light is given off directly below the arc. This is

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[illegible]

[illegible]

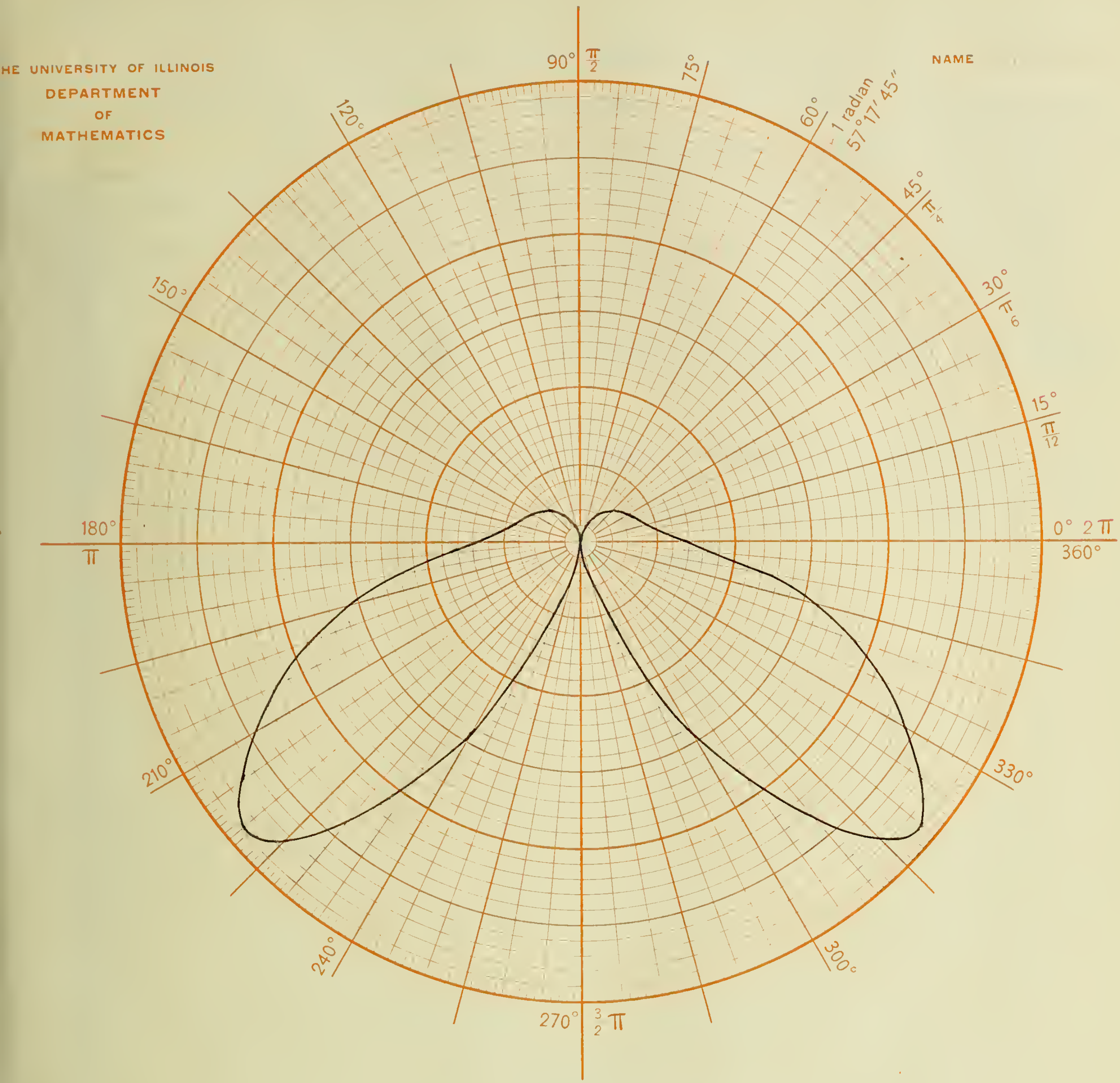


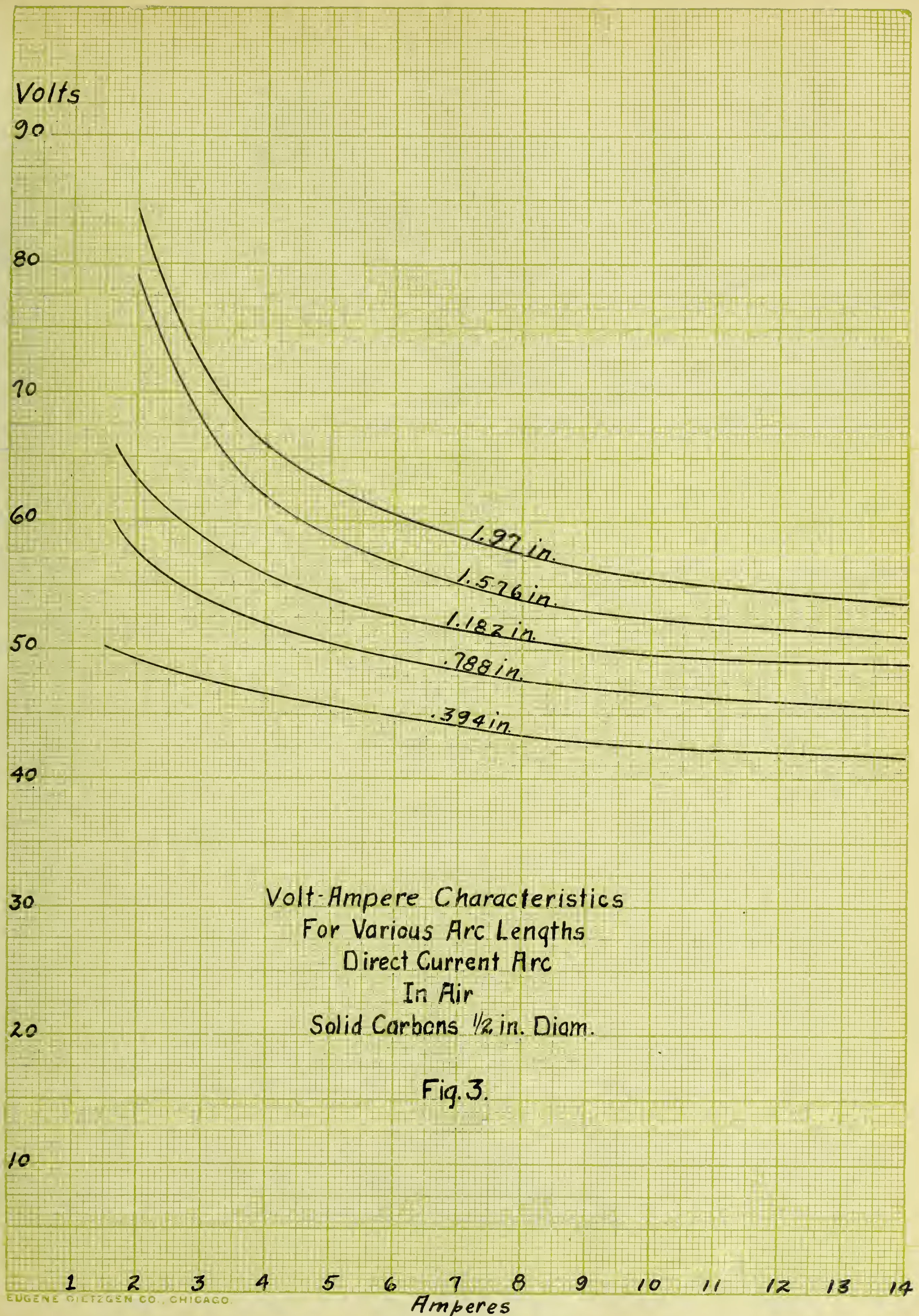
Fig. 2.

Typical Distribution Curve
for
D.C. Open Arc Lamp

due to the shadow cast by the negative electrode which is directly beneath the positive and hence obscures the light from the crater.

For open arcs, six to ten amperes and 42 to 52 volts are used. A common value is 47 volts and 9.6 amperes which, therefore, consumes 450 watts. Such a lamp was formerly rated at 2000 nominal candle power. This is far in excess of the mean spherical candle power. In fact the maximum value is probably about 1200 C. P.

Curves are given in Figs. III and IV showing the relations between current, voltage and arc length and also between currents, watts consumed and arc length.


Volts
90
80
70
60
50
40
30
20
10
1.97 in.
1.576 in.
1.182 in.
.788 in.
.394 in.
1 2 3 4 5 6 7 8 9 10 11 12 13 14
Amperes
EUGENE DIETZGEN CO., CHICAGO.
Volt-Ampere Characteristics
For Various Arc Lengths
Direct Current Arc
In Air
Solid Carbons 1/2 in. Diam.
Fig. 3.

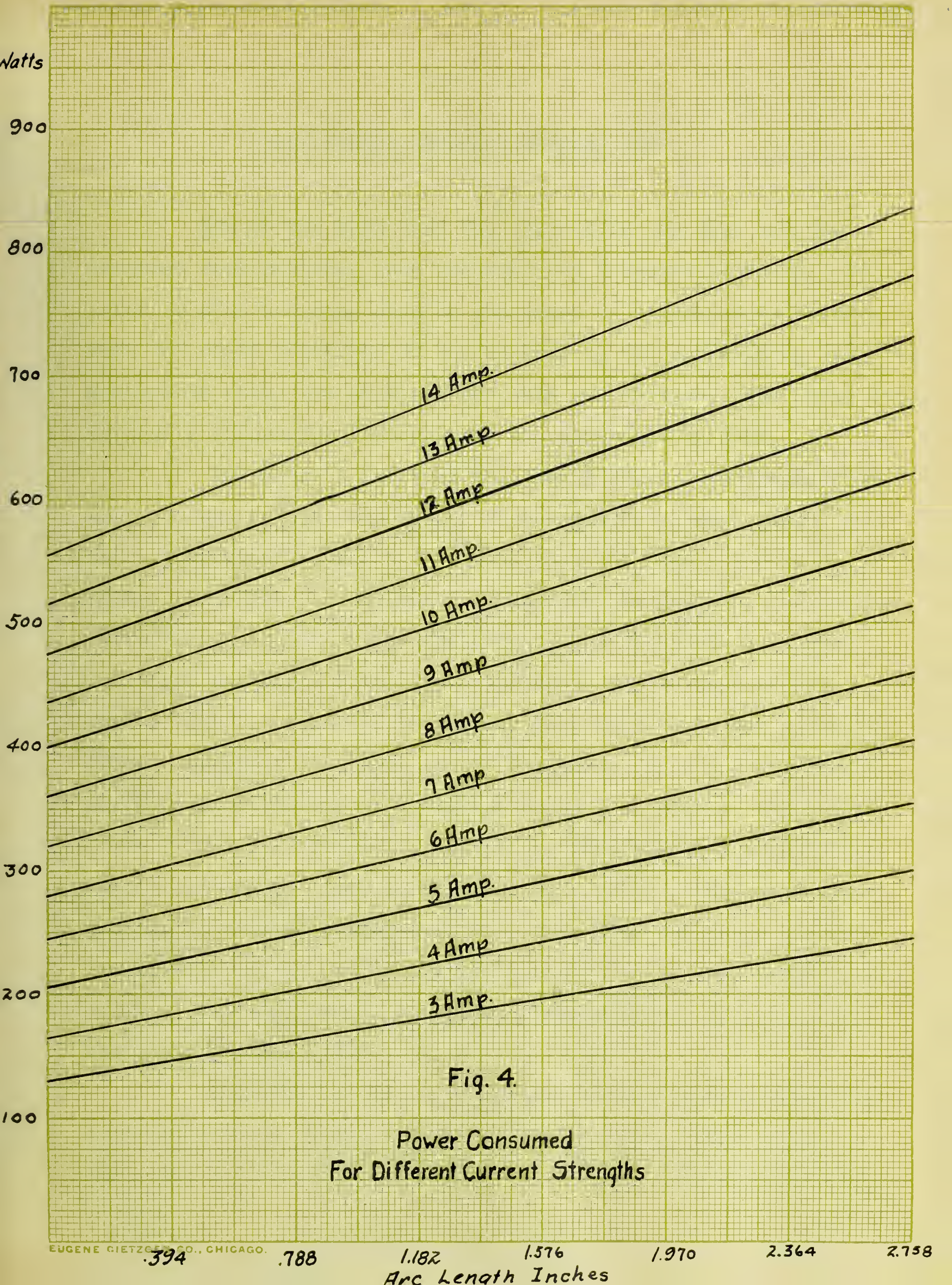


Fig. 4.

Power Consumed
For Different Current Strengths

THE DIRECT CURRENT INCLOSED ARC

Due to the fact that the carbons in the open arc are consumed very rapidly, they require very frequent trimming. In order to give a longer life to the lamp, it is necessary to prevent the rapid oxidizing of the carbons by the surrounding air. To accomplish this, the inclosed arc lamp was devised. The first commercially successful inclosed arc was perfected in 1894.

The present inclosed arc lamp differs essentially from the open arc in that the arc is surrounded by an oval globe of refractory glass from 5 to 7 inches long and from 2 1/2 to 4 inches in diameter. The smaller the bulb, in general, the better the efficiency, but if too small the glass is liable to become soft from the heat of the arc. The globe may be open at both ends or only at the top; the latter form being the most generally used. The rim at the open top is ground to fit a porcelain canopy through which the upper carbon passes and against which the globe is pressed by means of a spring, thus making the inclosure nearly air tight. This porcelain canopy being a good heat conductor, it remains cooler than does the globe and hence the grayish residue thrown off by the arc collects on it more readily than on the hot globe. This, of course, increases the efficiency by keeping the globe clean.

When the arc is first sprung in the inclosed arc, the conditions are much the same as in the open arc. The oxygen in the globe is, however, soon exhausted by combining with the car-

bon of the arc. A stable condition is reached in about 10 minutes when the bulb contains only heated CO and CO_2. A certain amount of carbon is set free or rather thrown out by the arc, and it is, therefore, customary to admit enough air to the bulb to consume this carbon in order to prevent its being deposited on the globe and thus blackening it. This air is admitted through the opening in the canopy through which the upper carbon passes, this opening being made a very little larger than the carbon rod. The electrodes in the inclosed arc have a tendency to form much the same as in the open arc, but this tendency is not nearly so pronounced since both carbons remain nearly flat ended. The positive carbon is consumed from 2 to 15 times as fast as the negative, depending on the relative size of carbons, the amount of air admitted to the globe and the lamp design. In properly designed lamps the positive carbon is consumed a little less 1/8 inch per hour. Therefore, since the positive is about 12 inches long, the carbons last from 100 to 150 hours per pair and hence enclosed lamps require trimming only about one-tenth as often as do open arc lamps. Because of the fact that all electrode impurities are deposited on the globe, thus reducing efficiency, it is very necessary that the carbons be quite pure. For this reason cored carbons can not be used. The carbons must also be straight and smooth and of uniform diameter so that they may pass through the small opening in the canopy without any difficulty. Hence only squirted or forced carbons can be used since those made by molding have a rib running the entire length of the carbon and are otherwise more irregular than the squirted type.

Hissing in the inclosed arc is much less prominent than in the open arc. Mrs. Ayrton found that in an absolutely air-tight inclosure hissing was totally absent for any current value or length of arc. This supports the theory given under the open arc discussion that an extension of the crater and a resulting in-rush of air is the cause of hissing. Flaming does not occur very often in the inclosed arc and it is not so pronounced as in the open arc. The zone of flame surrounding the arc in open arc is entirely absent in the inclosed arc due to a lack of oxygen to support it. There is a tendency to rupture or cut out the arc that is peculiar to the inclosed type. This is probably due to a gust of air entering the globe, cooling the arc stream and changing its resistance so very rapidly that the circuit is broken before the correct value of arc voltage to care for the new condition can establish itself. Due to the fact that the electrode ends are flat, the arc travels around causing the light to waver and appear to flicker because of the shifting shadow cast by the negative electrode.

Experience has fixed the proper value of E. M. F. at the arc at about 80 volts. It has been found that with less than this the arc will be too short to obtain complete combustion of carbon, with the result that the unconsumed carbon will be deposited in the globe. Greater voltage than 80 will cause too high electrode consumption and will also cause the violet component of the light to become too pronounced. At 80 volts the arc takes 5 amperes giving an energy consumption of 400 watts.

In the inclosed arc more energy is consumed in the arc stream and less in the crater than is the case in the open arc.

About 10% of the light produced is lost by transmission through the globe. However, the globe retains the heat around the electrodes which adds to the efficiency, the result being that the inclosed arc is nearly as efficient as the open arc.

The inclosed arc lamp is best suited to constant potential circuits because of the high voltage obtainable across the arc. When inclosed arc lamps were first used on series circuits, they were substituted on existing lines in place of open arcs. These circuits were supplied with energy by dynamos wound to furnish from 7 to 10 amperes. These values of current were too high for successful inclosed arc operation, as explained above, hence the lamps did not operate satisfactorily. In newer installations, however, the correct value of current has been used and other objections overcome, so that in the last few years inclosed arc lamps are being used more and more on high tension constant current circuits.

The distribution of light is slightly different than in the open arc; the maximum intensity occurring at 25° below the horizontal instead of 40° as in the open arc. Another high value, however, occurs at about 40°. The maximum value at 25° is probably due to the fact that the light coming from the crater is not cut off at that angle by the point of the negative electrode, as in the open arc, because both electrodes are nearly flat. A typical distribution curve for the inclosed direct current arc is shown in Fig. 5.

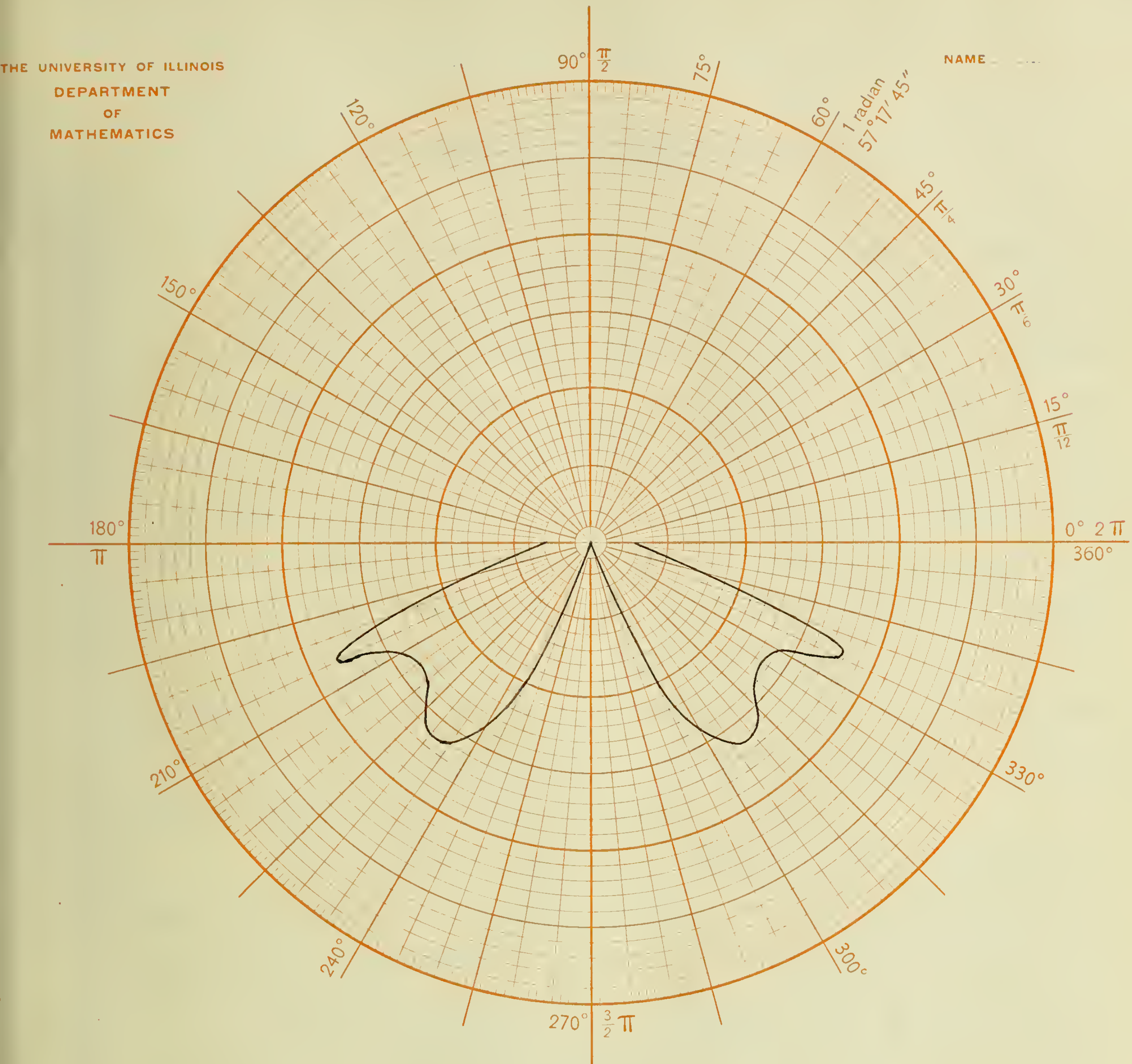


Fig. 5.

Typical Distribution Curve
for
Direct Current Inclosed Arc Lamp

THE ALTERNATING CURRENT OPEN ARC

The alternating current arc differs from the direct current arc in that the flame is not continuous, but is reversed in direction twice every cycle. This, of course, causes a flicker in the light which, however, is not apparent to the eye for frequencies of 60 cycles or greater. There is no crater in either electrode; in fact both burn to a point. The upper one is consumed 8% to 10% faster than the lower one due to being subjected to the ascending heat from the arc. Because the electrodes are consumed at nearly the same rate a focusing mechanism is usually employed to feed both electrodes at the same rate in order to keep the arc in about the same place. This necessitates a considerably longer lamp than is needed for direct current.

The ordinary commercial alternating open arc takes 15 amperes at 30 to 35 volts at the arc. This voltage seems unaccountably low in view of the fact that the minumum voltage with direct current is about 40 volts. However, the maximum value of the wave for an effective value of 35 volts is 35 x 1.41 or 49.5 volts which is ample to maintain the arc. The current used is much higher than in the D. C. arc due to the fact that it is necessary for the carbon vapor which bridges the gap to persist during the reversal of current. Heavy current and cored carbons cause this bridge to be maintained by furnishing a plentiful supply of carbon vapor.

Steinmetz has shown that a sychronously pulsating re-

sistance acts as a reactance. The resistance of the arc pulsates with the current being minimum when the current is maximum, and maximum when the current passes through zero. Hence the arc tends to cause a lag of the current in the circuit behind the E. M. F. Thus the product of volts at the arc and amperes flowing does not equal the watts consumed, the usual power factor being 75% for the open arc.

The efficiency of the alternating arc depends considerably on the form of current wave. A flat topped wave gives a higher efficiency than does a peaked topped wave, because the interval between maximum and zero value of current, during which the carbons cool off, is less in the flat topped than in the peaked topped wave. For the same reason a high frequency gives a somewhat higher efficiency than does a low frequency. The efficiency of the alternating arc is only about half that of the direct current open arc. This is probably due to the electrode tips of the alternating arc being cooler than the crater of the direct current arc because of cooling during the reversals of current. A compensating reactance coil or an auto transformer is used in the constant potential alternating current arc in place of the series resistance of the constant potential direct current arc. This saves the waste of energy in the resistance, and the result is that the efficiency of the whole lamp is not much smaller for the alternating current than for the direct current type.

A peculiar hum, having the same frequency as that of the supply current, is noticeable in the open alternating arc. This is due partly to the rapid vibrations of the air caused by the

expansions and contractions of the arc stream and partly to the vibration of the laminations forming the core of the inductance coils. This hum is entirely separate from the hissing which may occur in the alternating arc but is not so pronounced as the hissing of the direct current arc.

Because both electrodes are nearly equally heated, the light distribution is about equal above and below the horizontal, as shown by Fig. 6, the typical distribution curve. It is evident from this curve that a reflector must be used to throw downward the light which would otherwise go upward and be wasted.

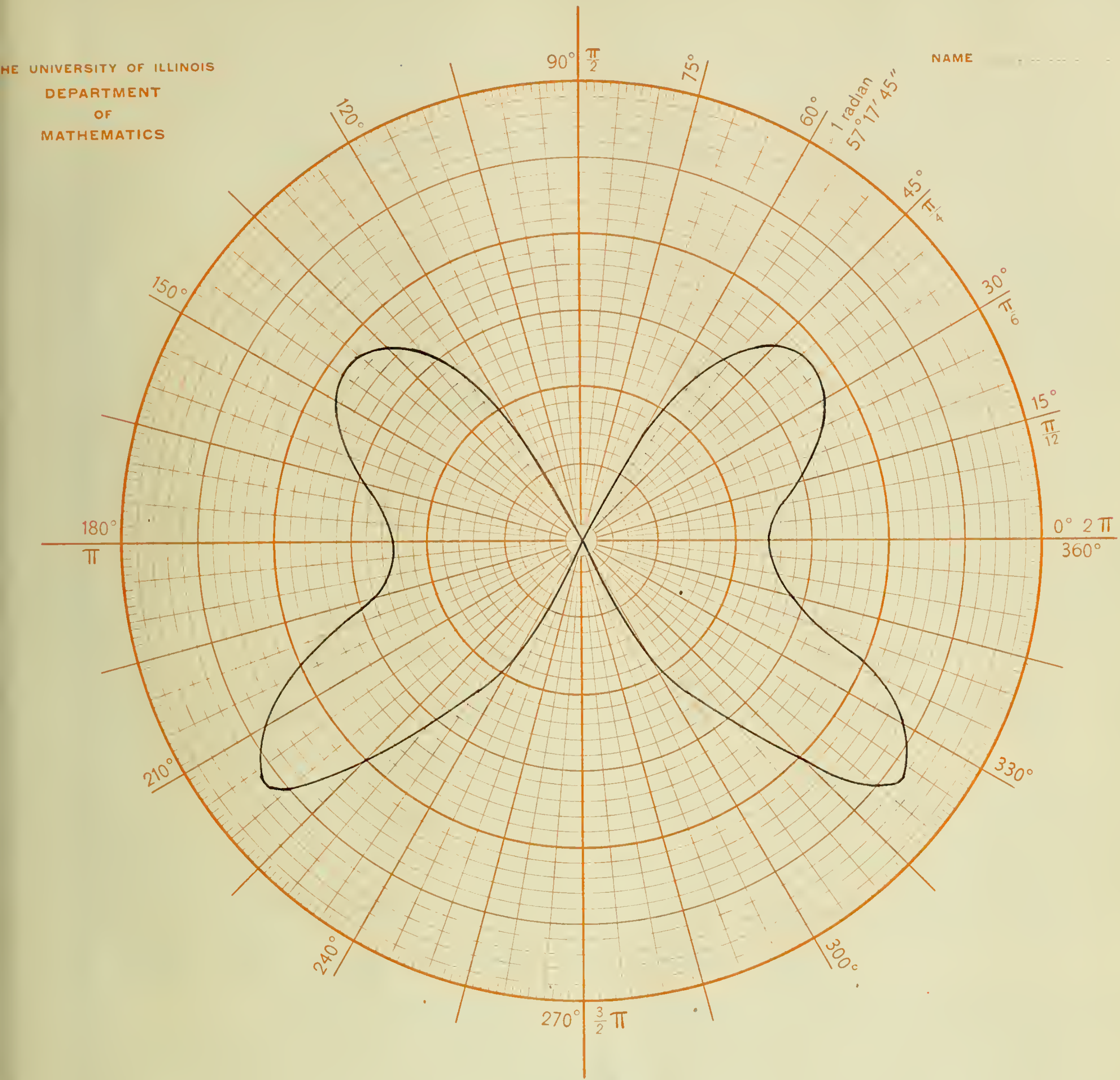


Fig. 6.

Typical Distribution Curve
for
Alternating-Current Arc Lamp
Open Type

THE INCLOSED ALTERNATING CURRENT ARC LAMP

Inclosed alternating current arc lamps have attained considerable prominence and are used very widely for street lighting. One or both carbons are cored and the result is large current and low arc voltage as compared to the direct current inclosed arc. Usually not more than one cored carbon is necessary because the globe gives protection from air currents which tend to destroy the arc stream, and because the deposit of impurities on the globe is too heavy with two cored carbons. Six amperes and 70 volts at the arc are the usual values giving an actual wattage of 390. The inductance coil usually consumes about 40 watts, making a total for the lamp of 430 watts.

The reactance coil, spoken of above, has taps leading from it at different points so that the lamp may be adjusted to give correct values of arc voltage for different terminal voltages, and frequencies over a considerable range.

In the inclosed alternating arc, there is an absence of the hum due to the contraction and expansion of the arc stream. This is probably caused by the retention by the globe of the heated gases around the arc. These gases tend to reduce the violence of the arc stream contractions. The hum due to the vibration of the iron parts of the lamps is reduced by clamping the laminations and supporting the vibrating parts with springs. An inclosed lamp mechanism for feeding both carbons similtaneously is usually com-

plicated and its construction presents several difficulties. Therefore, the lamp is usually so constructed that only the upper carbon is fed. This, of course, means a sacrifice of length of life, the average life being about 80 hours as compared to 100 to 150 hours for the direct current inclosed lamp.

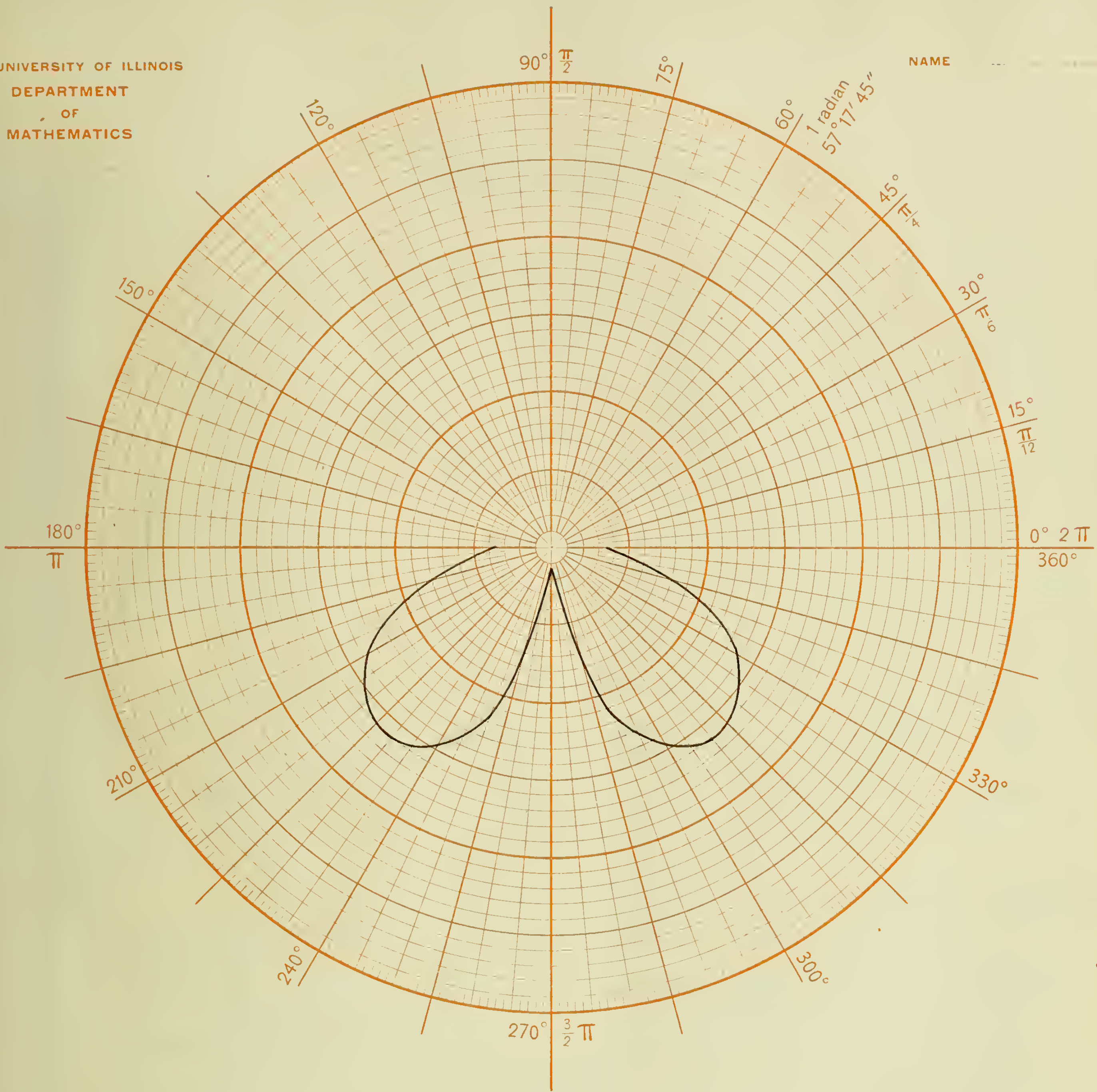


Fig. 7.

Typical Distribution Curve
for
Alternating-Current Inclosed Arc Lamp
With Reflector and Clear Inner Globe.

THE FLAMING ARC LAMP

In 1844 Casselman suggested mixing salts of copper, strontium, zinc, etc., with carbon to form arc lamp electrodes thus rendering the flame luminous. The first commercial yellow arc, as it is sometimes called, was placed on the market in 1899 by H. Bremer. The flaming arc carbons which are manufactured to-day consist of a carbon shell coved with a mixture of carbon and the fluoride of some alkaline earth, usually flouspar. This permits the arc to be drawn to a great length and rendered luminous at the same time. In the inclosed direct current arc only about 10% of the light comes from the arc stream, while 25% to 75% of the light (depending on length of arc, composition of carbons, etc.) is due to the vapor path in the flame arc.

The electrodes point downward and are inclined, making an angle of about 30° with each other. Thus they offer no obstruction to the light being thrown downward. This arrangement also allows the slag which is formed to drop into a receiver. This slag is a very poor conductor when cold and would prevent the starting of the arc unless disposed of. The electrodes pass through an economizer placed just above the arc. This economizer is a truncated metallic cone lined with porcelain. It acts as a heat retainer, concentrating it at the arc flame and also limits the air supply. It becomes covered with a white deposit from the arc and hence forms a good reflector throwing nearly all the

light into the lower hemisphere. Directly above the economizer a blow magnet is usually placed. Its function is to spread out the arc stream, thus increasing its area, and also to prevent the flame from destroying the economizer. The magnetic field set up by the arc produces the same effect which is very noticeable for large currents. In fact, for currents greater than 12 amperes, the blow magnet is often reversed to prevent the arc being "blown out" by its own magnetic field.

Both Bremer and Professor Wedding showed that an increase of the salt mixture up to a certain point caused an increase in efficiency as shown by the following table:-

PERCENT FLUOSPAR	M. S. C. P.	SPECIFIC ENERGY CONSP.
0	490	1.00
8	710	.70
15	1050	.475
20	1160	.43
25	1350	.37
30	1380	.36
35	1400	.35
40	1480	.34

The illumination is given in English candles. An opal globe was used; the lamp had a total energy consumption of 550 Watts with 55 volts and 10 amperes. By examining the table it will be noted that after 15% of salt has been added, an increase in salt does not cause a rapid increase in efficiency. Also at about 20% of fluospar the slag becomes objectionable and the arc unsteady. For these reasons about 15% of fluospar is the usual amount used. Calcium salts added to the electrodes cause the light to be

yellow, strontium, pink and barium,white. The yellow is the most popular and it gives the highest efficiency. When barium is used, giving a white light, the efficiency is only a little better than the open arc using pure carbon electrodes. In order to increase the steadiness of the long flaming arc the electrode diameter must be small. This,of course, tends to reduce the life and necesitates longer electrodes than would otherwise be necessary. Since the resistance of the electrodes is high due to the presence of the salts, the long electrodes cause a considerable loss. This is overcome partially by having a metallic vein or an electrolytic deposit of copper along the surface of the electrode.

The specific energy consumption, as seen above, is about 0.5 watt per M. S. C. P. This is 6 times better than the inclosed arc and 3 times better than the tungsten incandescant lamp. A table is given showing variation of specific energy consumption with current used.

AMPERES	VOLTS-ARC	WATTS	M. S. C. P.	SPECIFIC ENERGY CONSP.
6	55	330	480	.68
8	55	440	800	.55
10	55	550	1100	.5
12	55	660	1300	.5
15	55	825	1700	.49
20	55	1100	2250	.48

The light distribution curve shows the maximum intensity to be directly below the lamp. For this reason the lamp is not good for street lighting. The flame is unsymmetrical, the

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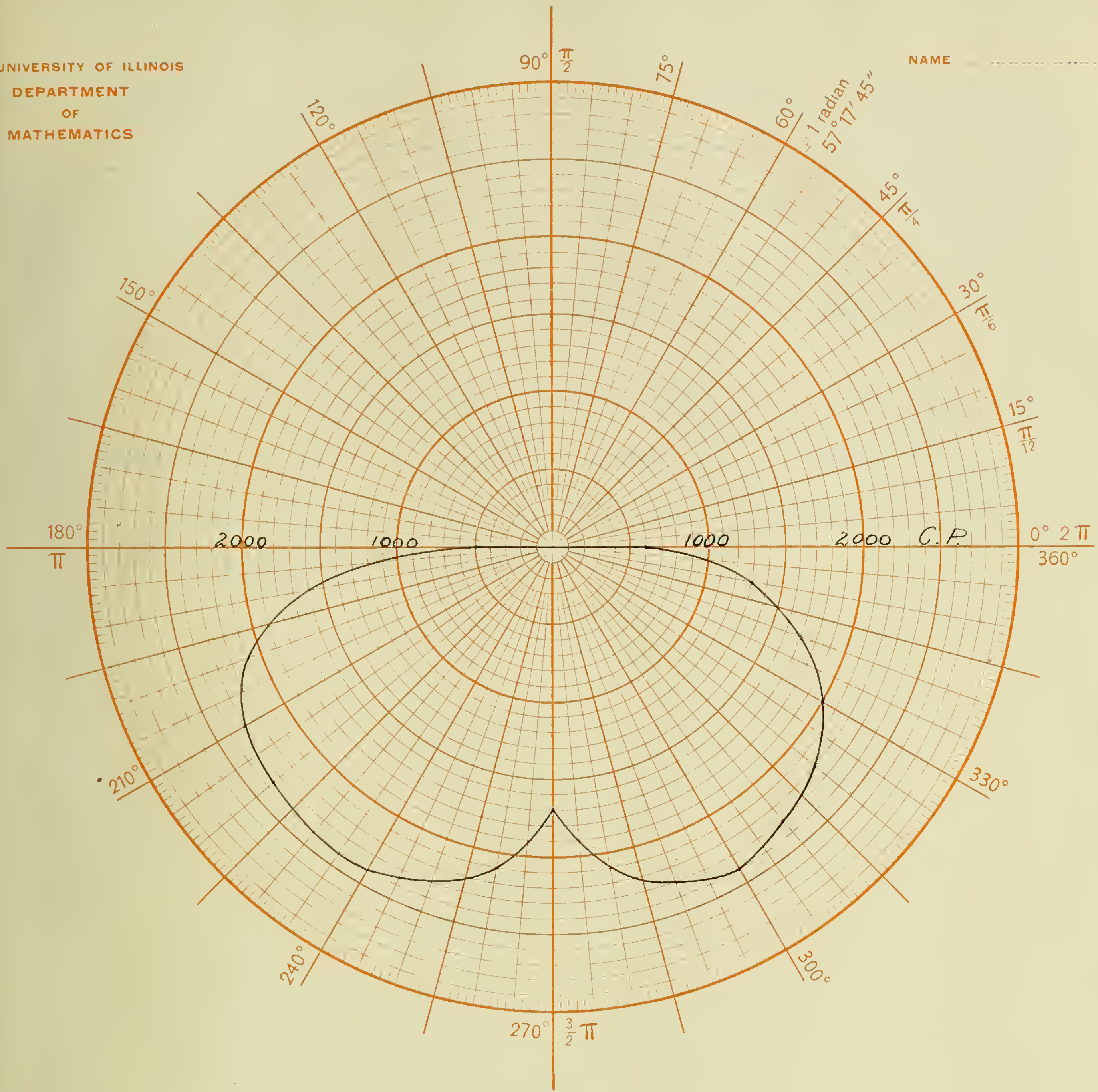

Fig. 8.

Typical Distribution Curve
for
Flaming Arc Lamp.
Yellow Flame
Inclined Electrodes.
With Ash Receiver

extension being greater in a flame through the carbons than in one at right angles to this. This unsymmetry is modified and the distribution equalized by the globe. A typical distribution curve is shown in Fig. 8 for a lamp with globe and ash receiver attached. The ash receiver obstructs part of the light directly beneath the arc.

The disadvantages of the flaming arc are the frequent trimming necessary, high carbon cost, noxious fumes and deposits on globes. The advantages are high efficiency and the "cheerfully pleasant" light given.

THE REGENERATIVE FLAME LAMP

Because of the rapid consumption of flaming arc lamp electrodes the trend of improvements of this type of lamp has been in the direction of increased electrode life. Perhaps the most successful developments in this direction have been those which employed the regenerative principle. In the regenerative flame lamp the electrodes are vertical, the negative being above and the positive below. The negative electrode is pure carbon, while the positive contains the light giving salt; hence the arc stream is fed by heat evaporation and not by electro conduction. The positive electrode consists of a cone of pure carbon, the cross section of which is a six-pointed star. The spaces between the ribs are filled with the fluorine salt giving an hexagonal cross section to the finished electrode.

The arc is tightly inclosed, no ingress or egress of gas or air being permitted. The gases from the arc pass to a chamber above the inner globe and from thence through side tubes on either side of the lamp to the bottom of the globe when they again enter the arc enclosure and start out anew. In the upper chamber and in the side tubes the heavier elements of the fumes are deposited on the cool metal, allowing only the light gases to enter the arc chamber a second time. This prevents deposits on the globe and the formation of slag or scoria on the electrodes.

In the regenerative lamp advantage is taken of the high intrinsic brilliancy of the flame by using a long arc. The usual value of arc length is between 3/4 and 1 inch,which gives an arc voltage of 70 volts, a current of about 5 amperes, and power consumption of 350 watts. Such a lamp produces about five times the illumination of the D. C. inclosed arc consuming the same power and has a much better light distribution for outdoor illumination. The length of electrode life is 70 hours compared to 14 to 16 hours for the open flaming arc. It would be expected that the side tubes would cast a shadow, but this difficulty has been almost entirely eliminated by using an opal outer globe. Alternating current regenerative flame lamps are also used to some extent. They have a shorter electrode life (60 hours) and are otherwise not quite so satisfactory as the direct current type.

THE METALLIC FLAME OR MAGNETITE LAMP

Experiments along the line of high efficiency and long burning electrodes has resulted in the magnetite or metallic flame lamp. Its high efficiency results from feeding into the arc stream some material which renders the flame intensely luminous. The magnetic oxide of iron or magnetite, together with some titanium oxide are the best materials for this purpose. The iron oxide furnishes a conducting vapor and the titanium oxide renders the flame highly luminous. A certain amount of chromium oxide is always added to prevent the too rapid evaporation of the material. This mixture of oxides is tamped into an iron tube, the end of which is then sealed in an arc, the whole forming the negative electrode. The positive electrode is usually made of copper, iron or some alloy. The alloy is the most preferable since when fused by the arc and become cold, when the lamp is not burning, it is still a good conductor and so facilitates the starting of the arc. The electrodes are arranged vertically. In the General Electric Company type the magnetite electrode is placed below, while in the Westinghouse type it is placed above. The fumes from the arc deposit as solids and hence would obstruct the light unless disposed of. These fumes are carried off by a draft of air which blows downward around the electrodes. This draft also fulfills another mission in causing the electrodes to burn squarely. The

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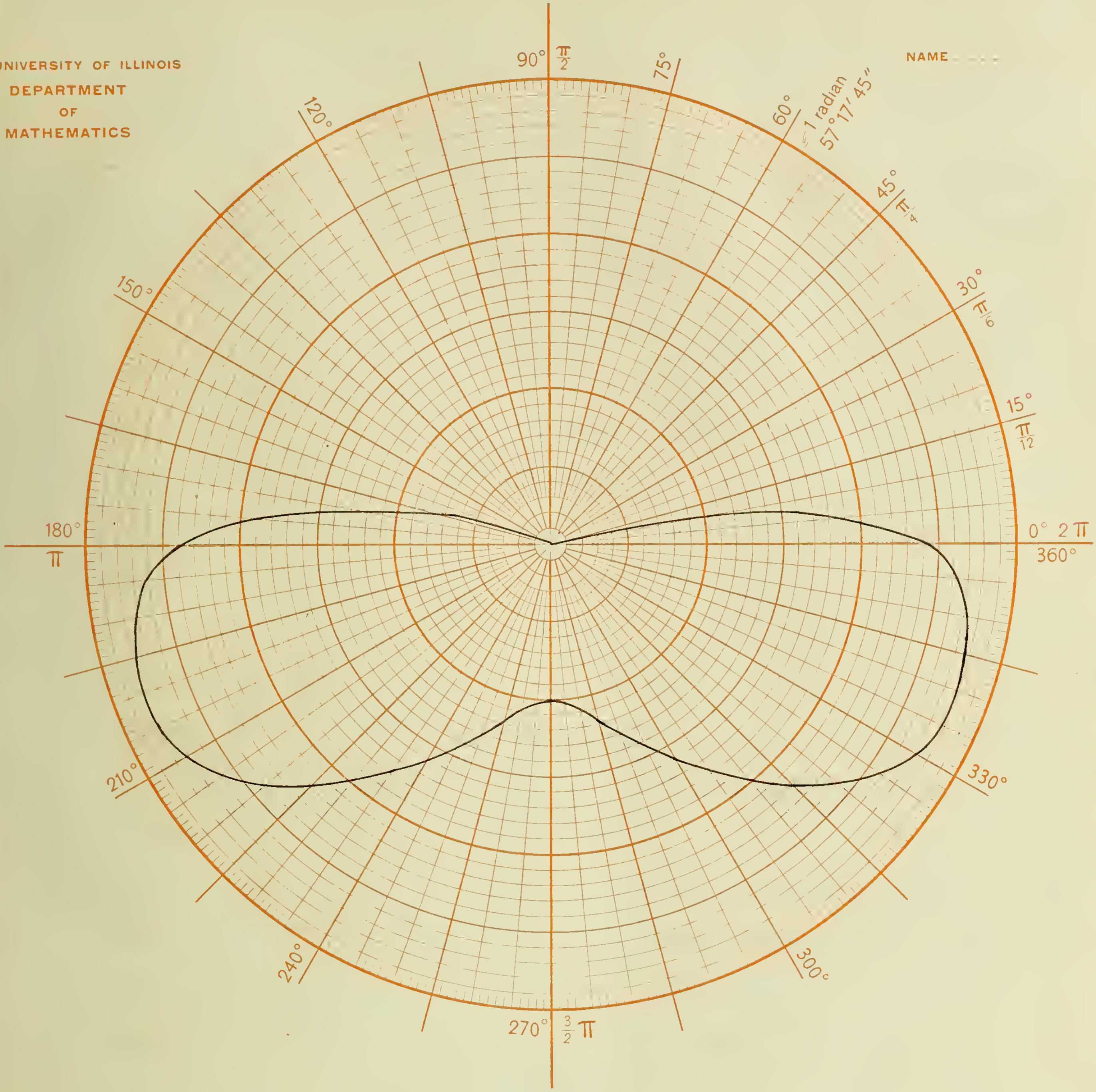

Fig. 9.

Typical Distribution Curve
for
Metallic Flame Arc Lamp
With Alba Globe and Reflector

life of the electrodes average 200 to 225 hours which is 50% better than the D. C. inclosed arc.

The usual arc voltage is 66 and the current 4 amperes. The efficiency is about .88 watt per M. S. C. P., which is three times the efficiency of the D. C. inclosed carbon arc.

The arc itself very closely resembles a candle flame since it has a bright zone and a non-luminous zone. The brightest point is near the negative electrode and is caused by a cone shaped mantle of luminous titanium oxide. A peculiarity of the magnetite arc when first developed was the dark spells which lasted for a minute or two. These dark spells were caused by the fact that the oxide of chromium is volatilized at a slower rate than either of the other two oxides and as a result, the negative electrode surface became covered with a pool of chromium oxide at intervals. Now the arc is rendered luminous by the titanium oxide, and since this material could not be fed with the stream when the electrode was covered with chromium oxide, a dark spell ensued. This defect was remedied by making the oxides inseparable by modifying the mixture. The light is a uniform pure white light, is very agreeable to most people and gives true color values. A typical distribution curve is shown in Fig. 9. This curve shows a maximum illumination at about 20° below the horizontal, thus making the lamp very desirable for the illumination of streets and large areas.

Alternating current luminous arc lamps are also manufactured. In this type, the magnetite electrode is usually placed below and is often formed of two separate converging sticks.

This alternating current type is not so successful and the electrodes cost more; hence it has not attained the popularity that the direct curve type enjoys.

THE TITANIUM CARBIDE ARC LAMP

Arc lamps whose electrodes contain titanium carbide give a very high efficiency in M. S. C. P. per watt. The negative electrode contains the light-giving material. These electrodes are made by mixing the carbide with oil or glycerine, forcing the mixture through a die and then drying and fireing the sticks. The sticks are then copper plated to increase their conductivity and to prevent the sticks from swelling and cracking while being burned. Titanium suboxide is sometimes used which gives a higher efficiency and makes electrode plating unnecessary. However, when suboxide is used, the stick consumes faster and large troublesome deposits form on the positive electrode, which necessitates an increased E. M. F. of 15 volts at the arc. The positive electrode is made of copper and is placed above the negative electrode. The copper is inactive and does not waste away appreciably. A button of titanium sometimes forms on the anode after the lamp has been running for some time. This results in unsteadiness of the arc and often causes hissing or a"positive blow", as it is called, accompanied by a jet of flame from the anode. The arc voltage then drops and the light intensity changes.

The efficiency of the titanium carbide arc is very good (about 0.51 watts per M. S. C. P.) The usual values of E. M. F. and current are 3 amperes and 95 volts. Such a lamp

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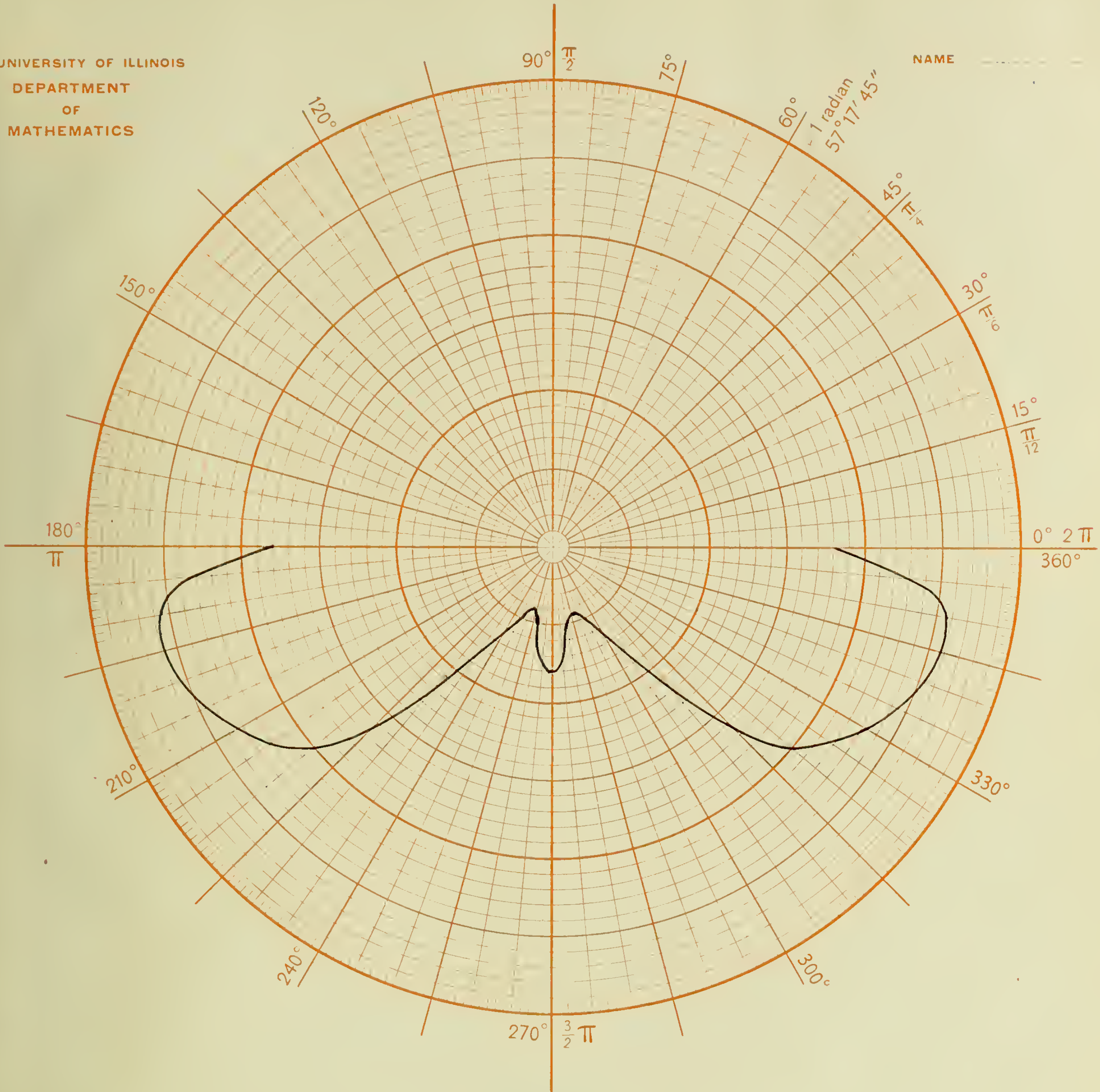

Fig. 10

Typical Distribution Curve
for
Alternating Current Luminous Arc.

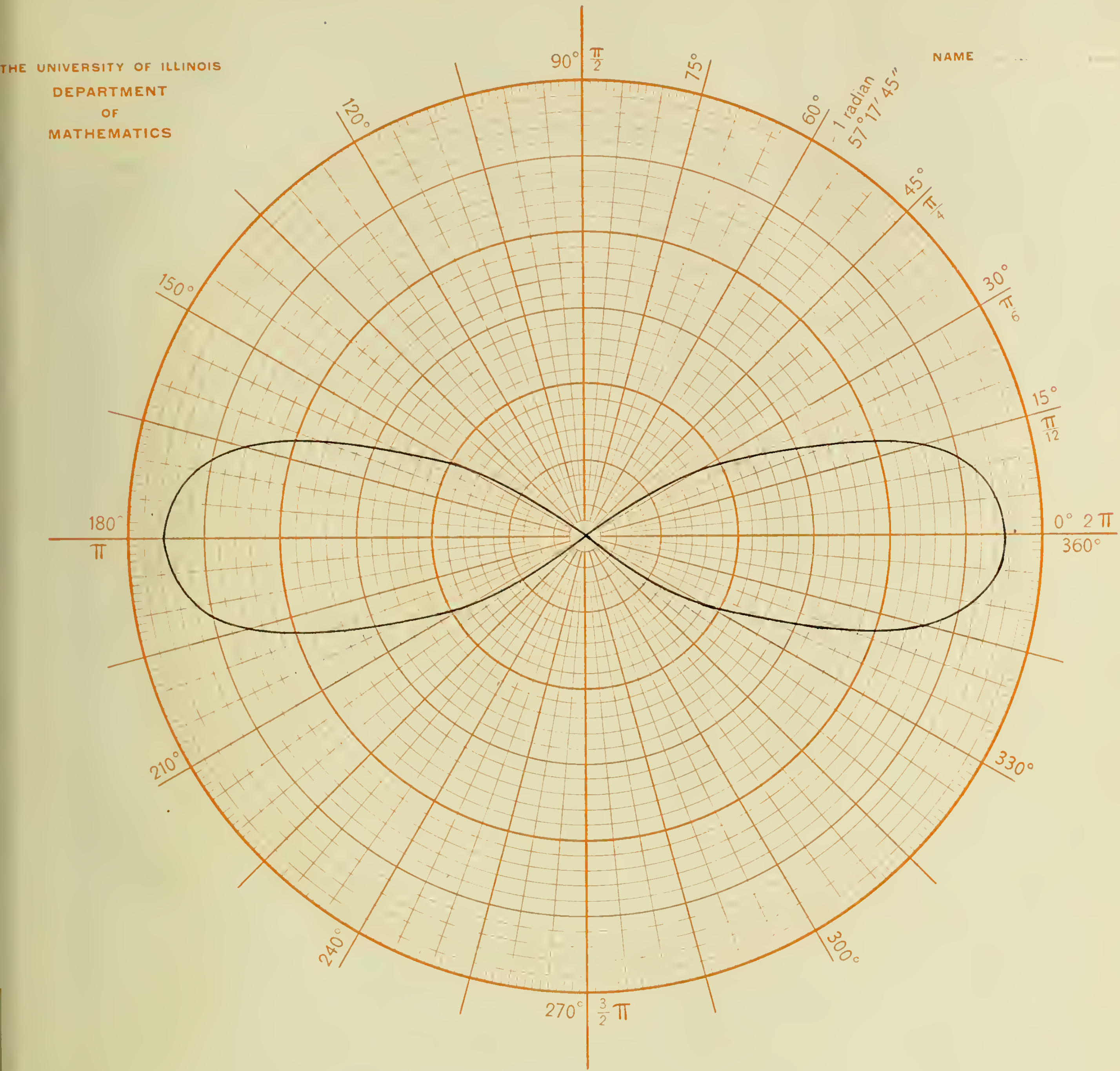

Fig. 11.

Typical Distribution Curve
for
Titanium Carbide Arc Lamp

gives a M. S. C. P. of about 535.

The light is nearly pure white with just a faint tinge of yellow. The light distribution is rather remarkable since the greatest illumination comes in a horizontal plane through the arc. This distribution is shown by Fig. 11.

The titanium arc has proved most satisfactory on a constant current circuit rather than on a low voltage multiple circuit.

THE PRESENT STATUS OF THE ARC LAMP

The tungsten lamp has, in the last few years, made serious inroads into that field of illumination in which the arc lamp formerly had a monopoly, namely, outdoor lighting. This is probably due to the fact that better light distribution can be gotten with the tungsten lamp than with the arc, and also to the fact that the efficiency of the tungsten lamp is higher than that of the carbon arc which until recently had been used entirely for outdoor lighting. In fact, the arc lamp would have soon been superseded entirely by the tungsten if it were not for the development of the flaming and luminous arc lamps. This transference of the light producing section from the carbon tips to the flame was a long step forward and, in Dr. Steinmetz' opinion, is the only chance the arc lamp has to hold its field against the tungsten lamp.

In making the arc stream the light-giving source, it at once becomes possible to use alternating current with all its attending advantages. It is a well known fact that the alternating carbon arc is very much less efficient than the direct current carbon arc in which nearly all the heat is concentrated in the crater instead of being distributed between both electrode tips, as in the alternating arc. In those lamps which derive most of their light from the arc stream, it makes little difference

whether direct or alternating current is used since the same amount of energy will be converted into light in either case.

The flaming arc has not attained very great popularity, due to the orange color of the light which does not give true color values and, in outdoor illumination, makes vegetation appear dead. If such salts are used in electrode manufacture that the light becomes white, then the efficiency is lowered. It is very likely, however, that a white flame arc with high efficiency will be invented in the near future. The orange light is quite attractive and is often used to draw attention. Because of the peculiar power of penetrating fog and smoke that the orange ray possesses, the flame arc has found quite an extended field in the illumination of foundries and other smoky places and in lighthouse and searchlight work.

The luminous arc is very well adapted to outdoor illumination. The color of the flame being white, it gives good color values and its light is so distributed that excellent illumination is obtained a considerable distance from the lamp. Another great advantage is the long intervals between trims which is of great importance in some cases. Several types of luminous arc lamps have been devised for interior illumination, and it is probable that they will obtain considerable popularity in this field. The great difficulty with the luminous arc is that large units have to be employed to take advantage of its wonderful efficiency. It is desirable to use a number of small units instead of a few larger ones in order to give a better distribution of light. This is not possible with the luminous arc since, for instance, a

decrease from 6.6 to 4.0 amperes in current consumption causes a decrease in power consumption of only 39%, and a decrease in light of 58%.

The direct current inclosed carbon arc, in spite of its low relative efficiency, is at present the most popular arc lamp for indoor lighting. This is due in a large measure to the unequaled light which it furnishes, being very close to sunlight, and giving almost absolutely true color values. Its freedom from fumes and quiet operation have also contributed largely to its popularity.

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